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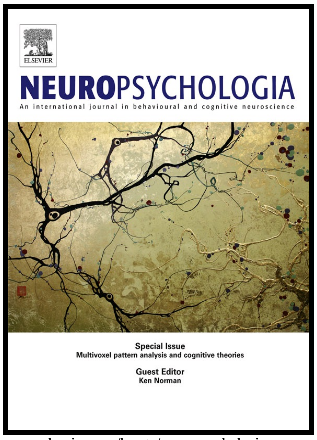

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The Good, the Bad, and the Average: Characterizing the Relationship Between Face and Object Processing Across the Face Recognition Spectrum

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ABSTRACT

Face recognition skills vary considerably both in the normal population and in various clinical groups, and understanding the cognitive mechanisms contributing to this variability is important. In the present study, we investigate whether a group of good face recognizers (high performers; HPs) perform qualitatively differently from a control group on tests of face, object and word recognition, and also compare them to a group of developmental prosopagnosics (DPs). Through a series of experiments, we (i) examine whether HPs are better than control subjects in face and object recognition, (ii) investigate if any dissociations among face, object, and word processing tasks can be demonstrated in the HPs, and (iii) compare the performance of the HPs to a group of poor face recognizers namely a group of DPs. Data from this DP group have previously been reported, but the analyses presented here are new. We find that HPs were significantly better than matched control subjects on tests of face and object recognition including a reading task, but they did not show significantly larger inversion effects on typical tests of face processing (the CFMT and the CFPT). There was no evidence of dissociations between face and object processing in the HPs when compared to controls, indicating superior performance across visual domains. In the DP group, however, we found significant dissociations between face and object recognition performance on a group level, indicating that face processing is disproportionally affected. On this basis, we propose that superior face processing in HPs rely on more general cognitive or perceptual processes shared with object processing. Hence, while face processing in DPs seems qualitatively different from the normal population, there is no such difference between average and high performing face recognizers. Thus, what underlies superior face processing in HPs might also underlie their superior performance with other stimulus classes and might be conceived as a general factor in the visual domain, a VG-factor, akin to the G factor in intelligence.

Keywords: Developmental Prosopagnosia, Superior Face Recognition, Face Recognition, Object Recognition

1. INTRODUCTION

“Super-recognizers” was a term introduced by Russell, Duchaine, & Nakayama (2009) to describe four individuals with exceptional good face recognition abilities. The super-recognizers scored 2 SD above the control mean on the Cambridge Face Memory Test long form (CFMT+); an extended version of the original Cambridge Face Memory Test (CFMT: Duchaine & Nakayama (2006)), showed disproportionately larger inversion effect on the Cambridge Face Perception Test (CFPT: Duchaine, Germine & Nakayama (2007)), and excelled at the Before They Were Famous test (Russell, Duchaine & Nakayama, 2009). These individuals have attracted attention because they seem to represent the opposite end on a continuum of face processing ability compared with individuals with so-called developmental prosopagnosia (DP); a disorder characterized by profound and lifelong difficulties with face recognition in the absence of any sensory or intellectual deficits or known brain injury (Duchaine, 2011).

Since the pioneering study by Russell et al. (2009) several other studies have reported individuals with superior face recognition skills (Bennetts, Mole, & Bate, 2017; Bobak, Bennetts, Parris, Jansari, & Bate, 2016; Bobak, Hancock, & Bate, 2016; Bobak, Pampoulov, & Bate, 2016; Bobak, Parris, Gregory, Bennetts, & Bate, 2017). Super-recognizers working with the police have received particular attention, probably because of the obvious usefulness of their face recognition abilities in this context (Robertson, Noyes, Dowsett, Jenkins, & Burton, 2016). Interestingly, the face recognition superiority does not seem to reflect, for example, an overall better memory capacity. Hence, a study by Ramon et al. (2016), which investigated the relationship between superior face recognition and superior memory, found that extensive training in memory techniques was not sufficient to boost performance on a face memory test to the level of super-recognizers. Whether the performance of super-recognizers is a results of better face perception has been investigated by examining portrait artists with extensive perceptual training (Devue and Barsic, 2016; Devue and Grimshaw, 2018; Tree et al., 2017). Portrait artists have been found to be more accurate than normal viewers on perceptual tasks involving both faces and other objects (Devue & Basics, 2016), but the association between face recognition abilities and production of faithful portraits might reflect stable individual skills that are independent of expertise (Devue & Grimshaw, 2018). The authors suggest that the advantages found for portrait artists might be based on pre-existing superior skills, rather than being a result of extensive practice. In line with this, Tree et al (2017) found no improvement in face recognition performance following a one year art course with substantial portraiture training, beyond what would be expected given practice alone. Thus, it seems that the perceptual advantage of portrait artists is not specific for faces, and is not a result of training.

With respect to the face perception of super-recognizers, more heterogeneous results have been reported, with only some super-recognizers performing better than normal viewers on the individual level e.g. when tested with CFPT (Bobak, Bennetts, et al., 2016). Tasks focusing on face matching abilities have also been used to test face perception, for instance using the Glasgow Face Matching Test (GFMT: Burton White & McNeill, (2010)), and the Models Face Matching Test (MFMT: Dowsett & Burton, (2015)), as well as a pixelated lookalike test, and a 1 in 10 face matching task (Bobak, Dowsett et al., 2016; Robertson et al., 2016). Results from these studies show that not all super-recognizers exceed the performance of control subjects on the individual level. Hence, differences between individual super-recognizers may reflect the use of tasks tapping different aspects of perception and/or with different psychometric properties. In comparison, group level analyses tend to show significant differences between super-recognizers and controls on tests of face perception, e.g. the CFPT (Russell, Chatterjee, & Nakayama, 2012; Russell et al., 2009), when matching single faces (Bobak, Dowsett, & Bate, 2016; Bobak, Hancock, et al., 2016; Davis, Lander, Evans, & Jansari, 2016; Robertson et al., 2016), and when spotting a face in a crowd (Davis & Tamonyt, 2017). Furthermore, the superior skills of super-recognizers have been argued to apply to both familiar and unfamiliar faces (Robertson et al., 2016; Russell et al., 2009), as well as unfamiliar disguised faces (Davis & Tamonyt, 2017).

Similarly, face inversion effects, which by some are considered indexes of face-specific processing (McKone & Robbins, 2011) or expertise (Diamond & Carey, 1986; Valentine, 1988), have generally also been reported to be larger in super-recognizers than in controls (Bennetts et al., 2017; Bobak, Bennetts, et al., 2016; Russell et al., 2009).

It is worth noting that the inconsistencies regarding individual performance of super-recognizers on perceptual tasks also seem to be characteristic of face recognition performance at large. As argued by Noyes, Phillips, & O'Toole (2017), a closer examination of individual performance shows that in several studies, not all individual super-recognizers score within the expected range of the group, but perform within the range of controls on different tasks (Bobak, Bennetts, et al., 2016; Bobak, Dowsett, et al., 2016; Bobak, Hancock, et al., 2016; Davis et al., 2016; Robertson et al., 2016). Further, some members of the control groups perform equally well or better than the super-recognizers and are thus well within expected range for superior face recognition. In accordance with these findings, some super-recognizers who excel on one task of face recognition might not excel on another (Bobak, Bennetts, et al., 2016; Davis et al., 2016).

Another potential problematic issue in the literature on super-recognizers concerns selection criteria. Super-recognizers are mainly identified as such by scoring 90 or above on the CFMT+, though higher thresholds have also been applied (Bobak, Pampoulov, et al., 2016; Davis & Tamonyt, 2017). When participants are selected based on their performance on a task of face processing, there is a risk for circular argumentation if the same individuals are afterwards assessed with tests of face processing that correlates highly with the selection task, and are then compared to controls. It is also problematic when control participants are pre-screened to eliminate subjects with superior or inferior abilities, before being included in a control group (Bobak, Dowsett, et al., 2016; Bobak, Hancock, et al., 2016). In some studies, however, super-recognizers are included to participate in a study based on self-reports of superior face recognition (Russell et al., 2009). This selection method reduces the risk of circular argumentation and seem ecologically valid. Generally, however, self-reported face recognition abilities only correlates moderately with objective assessments of face recognition abilities (Bate et al., 2018; Bobak, Mileva, & Hancock, 2018; Palermo et al., 2017), though some measures may show higher correlations than others (e.g. the PI20, Shah et al., 2015). Overall, it has been suggested that additional tests are required to reliably identify super-recognizers (Noyes et al., 2017).

Despite the inconsistencies in the performance pattern of super-recognizers across tasks, and the procedures by which they are identified, the existence of super-recognizers seems rather established. Nevertheless, only two studies have aimed to address directly whether and how these individuals differ qualitatively from individuals with average (normal) face processing skills. Russell et al. (2012) examined whether super-recognizers differed from controls in the use of shape and surface reflectance cues but found no evidence supporting such differences. In comparison, Bobak et al. (2017) presented still images of people in naturalistic social scenarios to super-recognizers, control subjects and DPs, and monitored their eye-movements. While the DPs did differ qualitatively from controls (the DPs spent more time examining the mouth, and less time examining the eyes) the authors concluded that the super-recognizers did not differ qualitatively from controls but rather seemed to represent the "top end" of normal variation, with the same typical face-processing mechanisms, as seen in normal viewers. The fact that DPs fixate more on the mouth region of faces may not be the cause of atypical processing, but a consequence. However, it does not change the fact that DPs perform qualitatively different from normal viewers and super-recognizers, who can extract more information from the central region of the face and do not need to resort to studying the mouth region.

Another way to assess whether super-recognizers differ qualitatively from controls is to address the question of face-specificity in super-recognizers: Is the superior performance confined to faces or does it reflect a more general proficiency in visual processing? This was examined in the study by Bobak, Bennetts, et al. (2016) who compared six super-recognizers and controls on matching of faces, houses and hands. The super-recognizers and controls did not differ in their ability to match objects, while most super-recognizers excelled at face matching. In an object recognition task, The Cambridge Car Memory Test (CCMT: Dennett et al. (2012)), another super-recognizer performed with almost perfect accuracy, while the remaining performed on level with controls. The authors suggest that these results favor a face-specific ability. One limitation of this study is, however, that no direct comparisons were made between the individuals' face and object recognition performance. Hence, it is not clear whether the super-recognizers were disproportionally better with faces than with objects relative to controls. The same is true of the study by Davis et al. (2016) who examined MET police identifiers and non-police super-recognizers. In comparison with a matched control group, both super-recognizers and the MET police identifiers excelled on tasks of face matching and face memory. In comparison, on a task of object recognition with old/new judgments of flowers, only a marginal significant (p = .072) group effect was found. However, no direct comparisons across face and object processing tasks were reported.

The limitation regarding direct comparisons between face and object processing performance has, to our knowledge, only been addressed in a recent study by Bennetts et al. (2017) who examined a young adolescent super-recognizer (O.B.). They found that O.B. exhibited a dissociation in recognition of faces and cars assessed with the CFMT and the CCMT. However, in a sequential same/different matching task with faces, houses, and hands no similar dissociation was reported. Accordingly, the dissociation may be specific to cars which also in other contexts has been found to be a category that behaves differently than other object categories (Gerlach & Starrfelt, 2018a; McGugin, Richler, Herzmann, Speegle, & Gauthier, 2012; Van Gulick, McGugin, & Gauthier, 2016), or it may be specific to certain paradigms. In sum, inconsistent results have been reported regarding super-recognizers' ability to perceive and remember faces, and the literature only yields sparse support to the notion that super-recognizers have a specific ability for face processing, which does not apply for other visual categories. Further, no direct evidence has yet been found in support of any qualitative differences in processing methods or strategies between super-recognizers and those used by the general population.

In the present study, we investigate the abilities of people who score in the high end on tests of face processing. These high performers (HP), as we will call them henceforth, contacted us reporting that they experienced being better than their peers at face recognition. They were pre-screened with CFMT Australian (CFMT-Aus: McKone et al. (2011)), and were invited to participate if they scored 90% or above. Their experiences of great face recognition abilities were further supported by their answers on the Faces and Emotion Questionnaire (Freeman, Palermo, & Brock, 2015), and the PI20 questionnaire (Gray, Bird, & Cook, 2017; Shah et al., 2015). While our participants would not necessarily be classified as super-recognizers, a denominator dependent on one specific test which was not available to us at the time of testing (the CFMT+) they were, nevertheless, in the very well performing range on the CFMT-Aus, and had experiences compatible with this performance. The HPs were assessed on tests of face and object recognition, and their abilities were compared to a matched control group, as well as the performance of a group of DPs. In comparison with previous studies, we directly examine whether the face processing abilities of the HPs are disproportionally better than their object processing abilities relative to the controls by means of dissociation analyses. With this setup, we aim to address the question of whether individuals with superior face processing ability differ qualitatively from the abilities of middle-range performers. An investigation of this question could focus on several aspects of their recognition abilities. However, logically the first investigation should be to study whether the superior abilities of high performers are specific to faces or whether it is based on a more general visual capacity. This more specific question is the main purpose of this study. Another interesting question is to examine if HPs represent the opposite end on a continuum compared with DPs, a question also discussed by Bobak et al. (2017) and Russell et al. (2009). We have a unique opportunity to address this question, because our study also includes a group of DPs, who were tested with the exact same set of tests as are used here with the HPs (Gerlach, Klargaard, & Starrfelt, 2016).

2. PARTICIPANTS, EXPERIMENTS AND PROCEDURES

2.1 Participants

2.1.1 High performers (HP). These subjects contacted us reporting that they experienced being better than their peers at face recognition. Some had read about super-recognizers on our website (ansigtsblind.dk), others had heard about us through friends or media. People who scored 90% or higher on the online version of CFMT-Aus (McKone et al., 2011), and who reported a personal history of being particularly good at recognizing other people, were invited to participate in the project. Participants answered the Faces and Emotion Questionnaire (29-items) (Freeman et al., 2015), and were also encouraged to complete a translated version of the PI20 questionnaire (Shah et al., 2015), available at a third-party commercial Danish website (not ours), in support of their personal experiences. In total, 19 subjects contacted us, and we included 14 participants (mean age 35.3 years [range 22-54], 12 women; 2 men) in the project. The remaining five subjects were excluded based on the following criteria; history of neurological disease, psychiatric disorders, brain damage or autism spectrum disorder.

For the control group, 14 subjects were matched on age, gender and educational level to the HPs. They were recruited through standard procedures at the Department of Psychology, University of Copenhagen, and received a reimbursement of 400 DKK for participating.

2.1.2 Low performers (developmental prosopagnosics (DP)). Background information on the group of individuals with DP (*N* = 10) can be found in Gerlach et al. (2016). Individually, they all performed significantly outside the normal range on the CFMT and the first part of the Faces and Emotion Questionnaire (29-items) (Freeman et al., 2015) compared with a separate control sample matched on age, gender and educational level. The control sample comprised 20 individuals. Note that data from these participants have been reported in previous publications (Gerlach, Klargaard, Petersen, & Starrfelt, 2017; Gerlach et al., 2016; Starrfelt, Klargaard, Petersen, & Gerlach, 2018). They are included here for a direct comparison with the HPs included in the present study.

All participants provided written informed consent according to the Helsinki declaration. The Regional Committee for Health Research Ethics of Southern Denmark has assessed the project, and ruled that it did not need formal registration.

2.2 The Faces and Emotion Questionnaire (FEQ)

The first part of the FEQ, which we report results from here, is a questionnaire that comprises 29 statements concerning everyday face recognition such as “I rarely confuse characters in TV programs”, and “I usually recognize my friends in old photographs” (Freeman et al., 2015). The statements are rated by the proband according to how strongly they agree or disagree with them using a four-point Likert-scale. The higher the score (maximum = 87), the more difficulties the person experiences with everyday face recognition.

2.3 The Cambridge Face Memory Task (CFMT)

In this task the participant is introduced to six target stimuli, and then tested with forced choice items consisting of three stimuli, one of which is the target (Duchaine & Nakayama, 2006). The test comprises a total of 72 trials distributed over 3 phases: (a) an intro-phase with 18 trials where the study stimulus and the target stimulus are identical, (b) a novel-phase with 30 trials where the target differs from the study stimulus in pose and/or lighting, and (c) a novel+noise phase with 24 trials where the target differs from the study stimulus in pose and/or lighting and where Gaussian noise is added to the target. The depended measure is number of correct trials. The maximum score is thus 72; chance-level is 24. There were two versions of the task, one with upright faces and one with inverted faces.

2.4 The Cambridge Face Perception Test (CFPT)

In this task, the participant has to arrange six facial images according to their similarity to a target face (Duchaine, Germine, & Nakayama, 2007). The images were created by morphing six different individuals with the target face. The proportion of the morph coming from the target face is varied in each image (88%, 76%, 64%, 52%, 40%, and 28%). The test comprises 16 trials, half with upright and half with inverted faces and the participants used the mouse to arrange the faces. Scores for each item are computed by summing the deviations from the correct position for each face. Scores for the 8 trials are then added to determine the total number of respectively upright and inverted errors. Hence, the depended measure is a deviation-score; the higher the score the poorer the performance, with chance-level at each orientation being a deviation-score of 93.3.

2.5 Difficult object decision tasks (ODT)

In these tasks the participants have to decide whether stimuli depict real objects or non(sense)-objects (see figure 1 for examples). The real objects were drawn from various classes including animals, vegetables/fruit, vehicles, furniture, tools etc.; for the complete list of items see Gerlach and Gainotti, (2016). All non-objects were chimeric combinations of real objects. The participants were instructed to press '1', on a serial response box, if the picture represented a real object and '2', if it represented a nonobject. Participants were encouraged to respond as fast and as accurately as possible. 160 pictures (80 real objects/80 non-objects) were presented in random order. All stimuli were presented centrally on a white background and subtended 3-5° of visual angle. The stimuli were displayed until the participants made a response. The interval between response and presentation of the next object was 1 s. The task came in three versions that differed in whether the stimuli were presented as full line drawings, silhouettes, or fragmented forms. The full line drawings of real objects were taken from the set of Snodgrass & Vanderwart (1980). The 80 chimeric drawings of non-objects were selected mainly from the set made by Lloyd-Jones & Humphreys (1997). These non-objects are line-drawings of closed figures constructed by exchanging single parts belonging to objects from the same category. The fragmented versions of the full line drawings were made by imposing a mask as a semi-transparent layer on the regular line drawings. This mask consisted of blobs of different sizes and shapes. The full line drawing and the mask were subsequently merged into a single layer yielding a fragmented version of the regular line drawing. The same mask was used for the generation of all fragmented stimuli. The silhouette versions of the regular line drawings were made by replacing the colour of each pixel within the interiors of the regular line drawings with the colour black. The order of pictures was randomized within each task. Prior to each of the three tasks, the participants performed a practice version of the upcoming task. Stimuli used in these practice versions were not used in the actual experimental conditions.

As in our previous study with DPs (Gerlach et al., 2016), performance in these tasks is measured in terms of discriminability indexed by *A*, which is a bias-free measure of sensitivity (Zhang & Mueller, 2005).

This measure varies between 0.5 and 1.0 with higher scores indicating better discrimination between objects and non-objects.

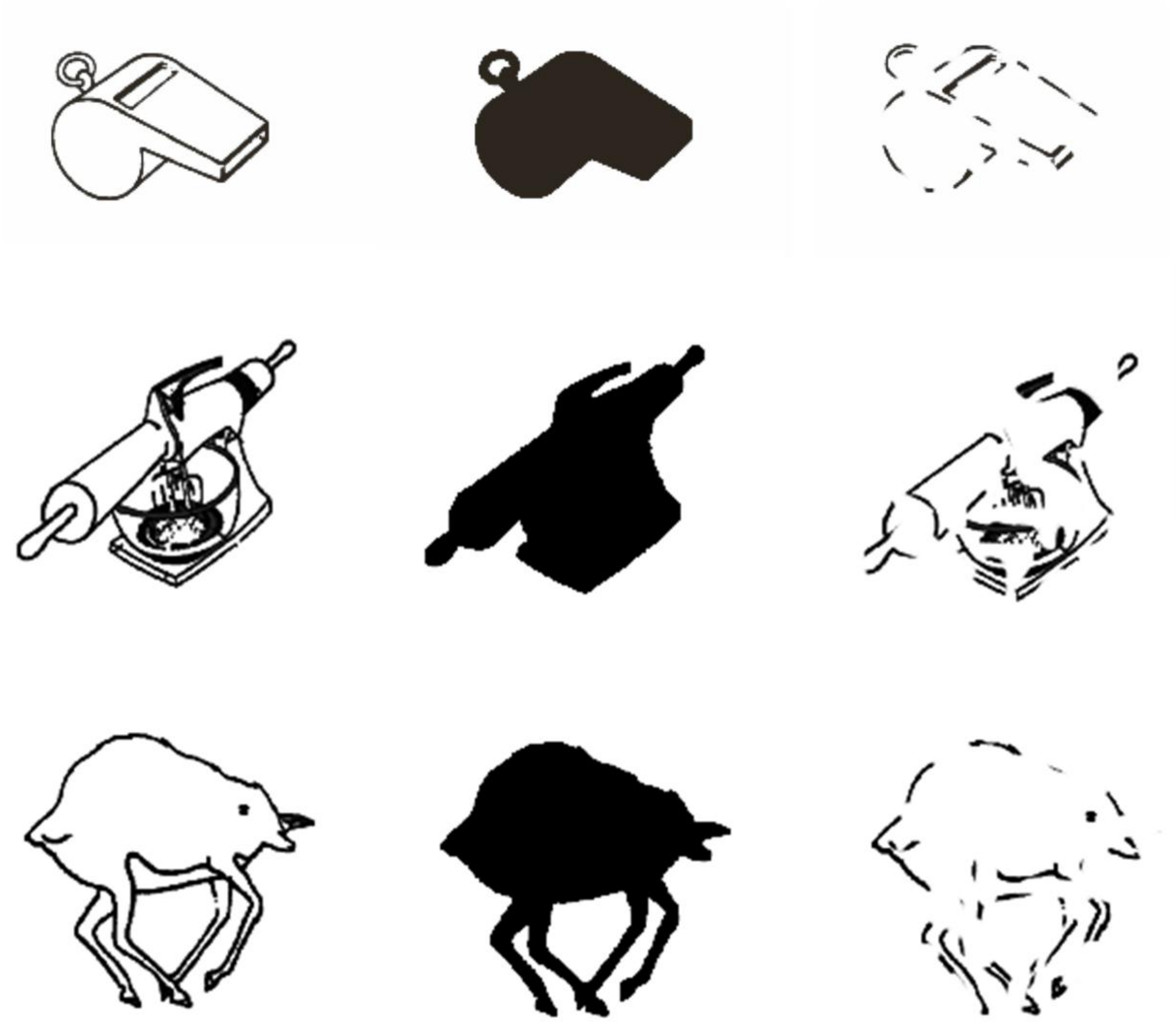

Figure 1: Examples of the stimuli used in the Object Decision Tasks. Upper panel: three versions (full drawing, silhouette, and fragmented) of a real object. Middle and lower panel: three versions of a chimeric nonobject.

2.6 Reading task

The participants were presented with 150 words of 5–7 letters (50 of each length matched for word frequency and neighbourhood-size) they were asked to read aloud as quickly and accurately as possible (Habekost, Petersen, Behrmann, & Starrfelt, 2014; Starrfelt, Nielsen, Habekost, & Andersen, 2013). RTs were measured by a voice key (a microphone connected to a serial response box). Because errors are quite low in this paradigm (on average < 1%: Starrfelt et al. (2018)) we only used the mean correct RT as the dependent measure for this experiment. RTs were trimmed by excluding RTs from trials deviating more than 2.5 SD for each individual at each word length, to exclude voice key errors. We included this task to examine whether the HPs proficiency would extend to processing of a stimulus category (words) that is usually assumed to be rather independent from face processing ability; also in DP (Burns et al., 2017; Rubino, Corrow, Corrow, Duchaine, & Barton, 2016; Starrfelt et al., 2018).

2.7 Navon's paradigm (Navon, 1977)

The participants were presented with large letters, either 'H' or 'S', that could consist of either smaller 'H's or 'S's. The experiment comprised four experimental blocks. In two blocks, the participants were required to report the identity of the large (global) letter, whereas they were to report the identity of the small (local) letters in the other two blocks (a selective attention paradigm). The blocks were presented in an ABBA design beginning with global identity judgements. The large letters were 4.1 cm wide and 5.5 cm high (3.91° × 5.25°) and the small letters were 0.5 cm wide and 0.7 cm high (0.47° × 0.67°). The fixation cross presented before stimulus onset was 1 cm wide and 1 cm high (0.95° × 0.95°). All stimuli were black presented on a white background on a computer screen. Participants performed a total of 48 trials in each block, 24 consistent (same identity of local and global elements) and 24 inconsistent (different identity of the local and global elements). The stimuli were shown at either the right or the left side of the fixation cross, with the centre of the global shape positioned 3.5 cm (3.34°) from the fixation cross. An equal number of stimuli within each block (n = 24: 12 consistent and 12 inconsistent) were presented to the right and the left. The order of position and consistency (consistent vs. inconsistent stimuli) was randomized. A trial began with a fixation cross presented in the middle of the screen for 1 s, which the participants were instructed to look at when present. This was followed by stimulus onset which was replaced after 180 ms. by a blank screen which remained until response. Responses were recorded via a serial response box.

Before each block, the participants performed 16 practice trials. Feedback was provided during the practice trials but not during the experimental blocks.

While different effects may be obtained with Navon's paradigm depending on exposure duration, masking, letter spacing, attentional demands etc. (Kimchi, 1992; Navon, 2003; Yovel, Yovel, & Levy, 2001), three effects are usually found: (i) a *global precedence effect*, with faster judgements of the identity of the large letter (the global shape) compared with the small letters, (ii) an *interference effect* with slower responses to inconsistent than consistent stimuli, and (iii) an *inter-level interference effect* with greater interference effects on local compared with global identity trials. Here we focus on the global precedence effect because we have found this effect to be reduced in individuals with DP and its magnitude to be systematically related to these individuals face recognition ability (Gerlach et al., 2017). Hence, we wanted to examine whether this effect would be larger for individuals with superior face processing ability than for controls. Following our previous studies, we index the global precedence effect as the standardized mean difference (Cohen's *d*) between RTs to Local Consistent and Global Consistent correct trials. In comparison with other indexes derived from Navon's paradigm this index, which we term the *Global-Local precedence index*, is pure, because it measures differences in global and local processing which are not confounded by interference effects (Gerlach & Krumborg, 2014; Gerlach & Poirel, 2018; Gerlach & Starrfelt, 2018a). The higher the score on this index, the faster are responses to global as compared with local shape characteristics.

The individual scores on the respective tests can be found in the supplementary material which also lists RTs to real objects and non-objects in the object decision tasks as well as RTs to the four conditions of Navon's paradigm.

3. THE VISUAL OBJECT PROCESSING ABILITIES OF HIGH-PERFORMERS

3.1 Statistical analyses

In the analyses presented below we assess whether the HP group differs from its matched control group on the dependent measures. This is done by means of point biserial correlation analyses which assess the strength and direction of potential associations between group membership and the dependent variable of interest. If a reliable association is found then the groups differ on the dependent measure. There are two advantages of this approach: (i) differences between groups are readily expressed in terms of an effect size (r_{pb}), and (ii) the *dissociation* analyses to be presented later are based on correlations between groups and task performance.

Given the relatively small sample sizes of the groups we assessed the credibility (significance) of the correlations using robust statistics by estimating the 95% CI of the correlations based on bias corrected bootstrap analysis (1000 samples). Hence, a correlation was considered credible if the 95% CI did not cross 0.

We first examined whether the HP group did in fact perform better with faces than the control group on the three measures of face processing: The FEQ, the CFMT, and the CFPT. We also examined whether the HP group exhibited a larger inversion effect with faces compared with the control group, as such effects have previously been reported in people with superior face processing performance (Bobak, Bennetts, et al., 2016; Russell et al., 2009). While it is debated what exactly the inversion effect reflects (Murphy & Cook, 2017; Tanaka & Gordon, 2011), it is often thought to be an index of face-specific processing (McKone & Robbins, 2011), though see Rezlescu, Chapman, Susilo, & Caramazza (2016) for a different interpretation. We examined two indexes of face inversion: (i) one based on the CFMT with upright faces – CFMT with inverted faces ($CFMT_{IE}$), and (ii) one based on the CFPT with inverted faces – CFPT with upright faces ($CFPT_{IE}$). Positive differences on these two indexes reflect better performance with upright relative to inverted faces.

To examine whether the HPs might also exhibit better performance with objects we compared their performance on the three tasks tapping object processing: Object decision with full line-drawings (ODT_{Full}), object decision with silhouettes ($ODT_{Silhouettes}$), and object decision with fragmented forms ($ODT_{Fragments}$).

Finally, we examined group differences on the reading task and our index of Global-Local precedence based on Navon's paradigm.

3.2 Results

3.2.1 Faces: As can be seen from Table 1, the HP group performed reliably better than the control group on both the CFMT and the CFPT, and the HP group also scored lower than the controls on the face recognition questionnaire (FEQ). These findings clearly suggest that the HP group exhibited superior face recognition skills on both objective tests and the self-report measure. The face processing advantage for the HP group was not confined to upright faces but was also apparent with inverted faces. Perhaps due to this general face processing advantage, the HP group did *not* exhibit inversion effects that were reliably larger than those exhibited by the control group.

	HP group		Control group		r_{pb}	95% CI
	Mean	95% CI	Mean	95% CI		
FEQ	5.9	3.2 : 10.1	16.7	12.4 : 21.8	*.54*	.20 : .83
CFMT Upright (Total correct)	68.1	65.9 : 69.9	58.6	54.7 : 62.3	*.64*	.44 : .80
CFPT Upright (Total correct)	21.3	16.7 : 25.3	38.4	32.3 : 45.7	*.65*	.41 : .84
CFMT Inverted (Deviation score)	49.8	46.2 : 53.6	44.4	41.5 : 47.0	*.41*	.13 : .66
CFPT Inverted (Deviation score)	50.4	42.8 : 58.4	63.9	54.5 : 73.4	*.39*	.02 : .69
$CFMT_{IE}$ (CFMT upright - inverted)	18.3	15.9 : 21.1	14.3	9.7 : 18.3	.32	-.02 : .56
$CFPT_{IE}$ (CFPT inverted - upright)	29.1	23.5 : 35.2	25.4	18.5 : 33.8	.14	-.23 : .52
ODT_{Full} (*A*)	.981	.976 : .984	.967	.958 : .975	*.49*	.29 : .67
$ODT_{Silhouettes}$ (*A*)	.965	.953 : .974	.948	.935 : .959	*.40*	.11 : .68
$ODT_{Fragments}$ (*A*)	.874	.848 : .899	.841	.816 : .866	*.34*	.03 : .62
Reading (Mean RT msec.)	493	467 : 520	580	545 : 616	*.59*	.37 : .77
Global – Local Index	.29	.01 : .61	.22	.003 : .43	.07	-.30 : .40

Table 1: The mean performance and its associated 95% confidence interval (CI) for each task for the high performers (HP group) and their control group. Also listed is the biserial correlation between each task and group (high performers vs. controls) and the 95% CI associated with each correlation. The 95% CI's were based on bias corrected bootstrap analysis (1000 samples). Reliable correlations are marked in *italics*.

3.2.2 Objects: As can be seen form Table 1, the HP group exhibited superior performance compared with the control group on all measures of object recognition performance.

3.2.3 Reading and global precedence effects: In line with the face and object recognition tasks, the HP group also read words reliably faster than the control group. However, the difference in the Global-Local precedence index did not differ reliably between the groups. Also, comparing the absolute RTs across the four conditions comprising Navon's paradigm revealed no significant differences between the groups (all p's > .86).

3.3 Interim discussion

The finding that the HP group performed reliably better than the control group on the CFMT and the CFPT confirms that the inclusion criteria had worked as intended in that they succeeded in singling out a group of individuals who performed in the high end of the face processing spectrum. The better performance of the HP group, however, was clearly not confined to faces. They also exhibited superior performance on the object recognition tasks and the reading task. In fact, the only measure on which the HP group did not differ reliably from the controls was on the Global-Local precedence index. Considered together these findings suggest that the HPs' superior performance is not face-specific. To the extent that inversion effects for faces provide more face-specific measures than performance with upright faces considered alone, the failure to find larger inversion effects in the HP group corroborates the picture of them having a higher *domain general* competence in visual object processing.

The failure to find larger inversion effects in the HP group departs from previous findings of superior face inversion effects in super-recognizers (Bobak, Bennetts, et al., 2016; Russell et al., 2009). In comparison with our HPs, these super-recognizers were classified by high-end performance (> 90% correct) on the CFMT+ which includes a fourth section with 30 very difficult trials (Russell et al., 2009). Hence, one explanation for the present discrepancy might be that some of our HPs (2/14) exhibited celling effects on the CFMT preventing them for obtaining higher inversion scores. While we acknowledge this possibility, we note that the HPs also did not exhibit reliably larger inversion effects on the CFPT which was not associated with floor effects (on the CFPT lower scores are associated with better performance). Considering that previous findings of larger inversion effects in super-recognizers were actually also based on the CFPT (and not the CFMT or CFMT+), the discrepancy thus remains. It is worth noting, however, that the inversion effect in the studies by Russell et al. (2009) and Bobak, Bennetts, et al. (2016) was measured as the difference between upright and inverted performance, *normalized to upright performance* [(upright - inverted)/upright]. In comparison, the inversion effects we calculate are based on the absolute difference between performance with upright and inverted faces. It is important to note that a consequence of the procedure adopted by Russell et al. (2009) and Bobak, Bennetts, et al. (2016) is that inversion effects get progressively larger the better the performance is with upright faces. As an example, individual *X* will obtain a higher inversion-score than individual *Y* even if the absolute differences in performance with upright and inverted faces are identical for these individuals provided that individual *X* performs better with upright (and inverted) faces than individual *Y*. Whether it is this scaled measure of inversion effects that yields a difference between super-recognizers and controls in the studies by Russell et al. (2009) and Bobak, Bennetts, et al. (2016) is impossible for us to determine, as raw scores for upright and inverted conditions are not provided in these papers. What we can say is that our HPs also exhibit a reliably larger inversion effect on the CFPT when we scale the inversion measure by performance with upright faces ad modum Russell et al. (r_{pb} = .44; 95% CI = .20, .68). This is not surprising considering that the HP group performed reliably better with upright faces to begin with. However, as we find no justification for the scaling procedure, which also departs from how inversion effects are commonly measured (Bruyer, 2011), we feel more comfortable concluding that inversion does not impact differently on the HPs group compared with the control group.

Before concluding that our HP group exhibit a domain general, rather than face-specific, visual processing advantage, we need to address in more detail how specificity is defined. What we have argued above is that we find no evidence for a face *selective* advantage in HPs. This, however, does not necessarily mean that the advantage for the HP group cannot be proportionally larger for faces than for objects and words; an issue we address in the next section.

4. ASSESSING POTENTIAL DISSOCIATIONS IN HIGH-PERFORMERS

4.1 Statistical analyses

In cognitive neuropsychology, special weight is put on dissociations, that is, on evidence suggesting that some capacity is preserved while another, typically related capacity, is impaired (Coltheart, 2001; Shallice, 1988). It is quite common that a dissociation is claimed if a person performs below 2SDs on task *X* but within the normal range on task *Y*. This approach was also adopted by Bobak, Bennetts, et al. (2016) in their study of super-recognizers, the only difference being that they examined whether their super-recognizers performed 2SDs *above* their controls on face processing tasks and within the normal range on tasks tapping object processing. They did, however, not apply statistical criteria for detecting dissociations. As pointed out by Crawford, Garthwaite, & Gray (2003), there are two problems with this approach: First, it is based on the (implicit) assumption that failure to reject the null-hypothesis regarding performance on task *Y* is proof of normality. This is a dubious assumption. Secondly, it fails to take into consideration the difference in performance between tasks *X* and task *Y*. In the extreme case, one could thus claim a dissociation if a person's score amounted to 2.01 SD on task *X* and 1.99 SD on task *Y*; a trivial difference of .02 SD.

To avoid these limitations Crawford et al. (2003) have suggested that a performance pattern must fulfil two criteria in order to count as a dissociation: (i) the person's performance on task *X* must differ significantly from that of the normal population, and (ii) the *difference* in performance of that person on tasks *X* and *Y* must differ significantly from the difference-scores of the normal population on tasks *X* and *Y*. In this way, a dissociation will be based on positive evidence entirely rather than on a mixture of positive and negative evidence. For further discussion regarding dissociation analyses, and why it is important to consider the correlation between tasks *X* and *Y* in the normal population, see Gerlach, Lissau, & Hildebrandt (2018).

If a dissociation is revealed by means of the method described above, it may be either a strong dissociation or a putatively classical dissociation. A strong dissociation refers to a performance pattern where an individual's scores deviate significantly from the control sample on *both* tasks *X* and *Y*, *and* where the individual's difference between tasks *X* and *Y* exceeds what can be expected in the normal population. In comparison, a putatively classical dissociation refers to a performance pattern where an individual's scores deviate significantly from the control sample on one of the tasks but is within the normal range on the other, *and* where the individual's difference between tasks *X* and *Y* exceeds what can be expected in the normal population. The reason why the classical dissociation is termed 'putative' is that failure to reject the null-hypothesis for one of the tasks does not really, as argued above, constitute evidence of normal performance on that task.

The logic of testing for dissociations in single cases can also be applied to testing for dissociations between two groups of subjects, and Crawford, Blackmore, Lamb, & Simpson (2000) have developed a test/program "Differential_deficit.exe" for this exact purpose. In this test, it is estimated whether the correlation between groups and performance on task *X* is significantly different from the correlation between groups and performance on task *Y* taking into consideration the correlation between the two tests for the whole sample and the size of the sample. In the following we apply this procedure for assessing whether the HPs exhibit a dissociation between performance on the face processing tasks (the CFMT and the CFPT) and the three ODTs plus the reading task. Should a dissociation be revealed, it would amount to a strong rather than a classical dissociation because we have already established that the HP group differs reliably from the controls on both the face and the object processing tasks. This approach should also be more sensitive than an approach based on examination of single cases because group level analyses have more statistical power than single case level analyses.

The statistics used for the dissociation analyses can be found in Table 1, which lists the correlations between groups and tasks, and in Table 2, which list the correlations between the tasks themselves.

4.2 Results

As can be seen from Table 2, we found no evidence for a strong dissociation between performance on the CFMT and performance on the three ODTs in the HPs when referenced to controls. The same were true for the comparisons between performance on the CFPT and the three ODTs. This is reassuring because the CFPT was not subject to any floor effects that might have reduced task differences. Finally, there were also no evidence for dissociations between the face processing tasks and word reading.

	Task correlation (*r*)	***p*-level of dissociation analysis**
CFMT & ODT_{Full}	.29	.43
CFMT & $ODT_{Silhouettes}$	.16	.26
CFMT & $ODT_{Fragments}$	.08	.19
CFMT & Reading	-.44	.75
CFPT & ODT_{Full}	-.44	.33
CFPT & $ODT_{Silhouettes}$	-.46	.14
CFPT & $ODT_{Fragments}$	-.39	.09
CFPT & Reading	.70	.61

Table 2: Correlations between tasks for the whole sample (high performers and controls) and the significance level of the dissociation analyses performed on the tasks (Crawford et al., 2000).

4.3 Interim discussion

Considering the results so far, we have established that our group of HPs evinces neither a specific nor a disproportional processing advantage for faces relative to objects. This contrast with the findings reported by Bobak, Bennetts, et al. (2016) who reported that at least some of their super-recognizers performed significantly better on some of the employed face processing tasks while performing within the normal range on object processing tasks. We see two potential reasons for this discrepancy. (i) While we have little reason to suspect that our negative findings are due to ceiling/floor effects, cf. the discussion above, we cannot exclude this possibility entirely; at least not for the comparisons involving the CFMT.

Indeed, and as mentioned earlier, the criterion adopted by Bobak, Bennetts, et al. (2016) for classifying an individual as a super-recognizer (> 90% correct in the CFMT+) seems more stringent than our criteria for classifying an individual as a HP, and this might lead to larger task differences. Having said this we will note that our approach was more sensitive in another respect in that we assessed differences based on group level analyses which are more powerful than single case analyses. Accordingly, what our approach might lack in sensitivity concerning picking out only the absolute best performing individuals is compensated for by higher statistical power. (ii) The conclusion of Bobak, Bennetts, et al. (2016) that some (3/6) of their super-recognizers exhibited face-specific proficiencies was based on superior performance with faces and within normal range performance with objects. However, there were no formal analyses of whether the differences between the face and object processing skills of these super-recognizers actually exceeded what could be expected in the normal population. The same limitation applies to the study by Davis et al. (2016) who reported large group effects for faces but only a marginally significant effect for objects. As discussed above, this limits the strength of the findings because they are then partly based on null findings (lack of a difference between the individual and the control sample for one of the tasks). As we have argued elsewhere (Gerlach et al., 2018), this is particularly worrisome in single case studies because they are typically characterized by low statistical power (few controls) which leaves a lot of room for Type 2 errors (false negatives). This particular concern does not apply to our findings because they are based on group statistics. Indeed, it may be the greater power of our group based analyses that made us able to detect superior performance with objects in our HPs. To our knowledge, only one study has reported a statistically significant dissociation between objects and faces in a super-recognizer (Bennetts et al., 2017). This dissociation, demonstrated in an adolescent, was only found in comparison with cars – an object class that has been suggested to stand out compared with other object classes (Gerlach & Starrfelt, 2018a; McGugin et al., 2012; Van Gulick et al., 2016) – and not compared to houses or hands. The authors concluded that face and object recognition are dissociable during development.

In contrast, the similarities between our findings from high performers, and those from super-recognizers (e.g., Bobak et al., 2017; Russel et al., 2009) suggest that these processes are not dissociable in adults, and that the operations underlying superior face processing may not be face-specific.

5. DO HIGH-PERFORMERS DIFFER QUALITATIVELY FROM OTHERS IN FACE PROCESSING?

As mentioned in the introduction, there has been discussion of whether individuals with superior performance in face processing differ qualitatively from the normal population or whether they represent the high end on a continuum (Bobak, Bennetts, et al., 2016; Noyes et al., 2017; Russell et al., 2009). Russell et al. (2009) argued that if their super-recognizers were about as good at face processing on a given test as DPs were bad, this would suggest that super-recognizers and DPs might simply occupy different ends on a broad continuum of face processing ability. As support for this proposition they noted that their super-recognizers scored around 2SDs above control mean on the CFMT+ whereas DPs scored around 2SD below controls on the CFMT. However, considering that their super-recognizers and DPs were selected according to whether they departed ± 2SD from the mean of the controls, it does not seem that surprising that the performance of the two groups were mirror images of each other. Had a more lenient criterion been adopted for classifying DPs as opposed to super-recognizers, or the reverse, the outcome would probably have been less balanced.

Another problem with the approach by Russell et al. (2009) is that it is one-dimensional, as only one test is considered at a time. Without any other anchoring point this means that any difference between groups will always be expressed as a distance along the same continuum (one test). Consequently, no matter how great a difference is between superior performers and their controls, it is not possible to conclude anything other than the superior performers reflect the high end, the very high end, or the extreme high end on a continuum depending on how conservatively they are selected. What is needed is evidence that the groups' performance on a given task, say face processing, differs more than one would predict given their performance on another related task, say object processing. In that case, the group difference would be context-specific which is more suggestive of a qualitative difference. Furthermore, the more related the two tasks are in terms of processing demands, the more surprising and informative will a group difference be (Gerlach, Lissau, & Hildebrandt, 2018). This dissociation approach is the one we have adopted here, and from our results there is no evidence suggesting that the HPs' face processing abilities differ qualitatively from what we would expect given their performance with visual processing of other classes of stimuli (objects and words). This lines up nicely with recent results from a study of eye-movement patterns in super-recognizers, finding superior performance, but no qualitative difference in processing between super-recognizers and controls (Bobak et al, 2017), as well as a recent review on superior face processing skills (Noyes et al., 2017). It is important to note, however, that even if such a dissociation is found – and it of course may be – this will not imply that individuals with superior face processing skills, be they high end performers or super-recognizers, are no longer at the high end of a broad distribution of face processing ability. Per definition they always will be. It would 'merely' mean that their position on this continuum may be driven by a special capacity unique to them, or excess of such capacity relative to other individuals, that is disproportionally more useful for face processing than for processing of other stimulus classes. Considering this, the question of whether individuals with superior performance in face processing differ qualitatively from the normal population or whether they represent the high end on a continuum is ill-posed.

If individuals with superior face processing skills do not differ qualitatively from individuals with medium processing skills, as our results suggest, does the same apply to individuals with inferior processing skills? This question is the topic of the next section.

6. DO LOW-PERFORMERS DIFFER QUALITATIVELY FROM OTHERS IN FACE PROCESSING?

To examine whether individuals with poor face processing skills differ in a qualitative manner from individuals with medium processing skills we compared the performance of the DPs and controls reported by Gerlach et al. (2016) using the dissociation procedure applied for the HPs described above. This comparison is particularly interesting as the DPs performed the exact same tests as did the HP group, and in many respects seem to pose a mirror image of the HPs. In the first section below, we present the results for the group comparisons, which for the most part have been reported elsewhere (Gerlach et al., 2017, 2016; Starrfelt et al., 2018). The dissociations analyses, however, have not been presented previously. Based on the same methods, Starrfelt et al. (2018) showed a dissociation between word and face recognition, but data from the present reading test was not included in this analysis.

6.1 Group difference results

6.1.1 Faces: As can be seen from Table 3, the DP group performed reliably worse on all tasks. Like the HPs, these differences were not confined to upright faces but also inverted faces. However, unlike the HPs, the DPs differed from their controls in the magnitude of the inversion effects with faces, with these being markedly reduced.

	DP group		Control group		r_{pb}	95% CI
	Mean	**95% CI**	**Mean**	**95% CI**		
FEQ	60.1	55.5 : 64.7	21.6	15.7, : 27.3	*.88*	.79 : .94
CFMT Upright (Total correct)	36.5	33.0 : 39.9	60.6	56.7 : 64.4	*.84*	.73 : .92
CFPT Upright (Total correct)	63.7	53.2 : 76.0	38.9	34.0 : 43.8	*.69*	.46 : .85
CFMT Inverted (Deviation score)	31.6	28.6 : 35.0	43.7	40.1 : 47.3	*.62*	.41 : .81
CFPT Inverted (Deviation score)	76.5	67.6 : 86.3	64.7	59.5 : 69.3	*.43*	.04 : .71
$CFMT_{IE}$ (CFMT upright - inverted)	4.9	0.6 : 8.8	16.9	13.8 : 20.7	*.62*	.44 : .76
$CFPT_{IE}$ (CFPT inverted - upright)	12.7	5.3 : 20.0	25.9	20.1 : 31.7	*.53*	.25 : .74
ODT_{Full} (*A*)	.938	.914 : .956	.953	.939 : .965	.15	-.22 : .49
$ODT_{Silhouettes}$ (*A*)	.873	.843 : .903	.914	.898 : .928	*.50*	.10 : .76
$ODT_{Fragments}$ (*A*)	.782	.736 : .827	.798	.770 : .823	.05	-.40 : .20
Reading (Mean RT msec.)	576	521 : 634	524	495 : 556	.32	-.04 : .61
Global – Local Index	.04	-.06 : .53	.49	.26 : .71	*.35*	.02 : .61

Table 3: The mean performance and its associated 95% confidence interval (CI) for each task for the developmental prosopagnosics (DP group) and their control group. Also listed is the biserial correlation between each task and

group (DP group vs. controls) and the 95% CI associated with each correlation. The 95% CI's were based on bias corrected bootstrap analysis (1000 samples). Reliable correlations are marked in *italics*.

6.1.2 Objects: Compared with the HP group, that differed from its control group on all measures, the DP group only differed reliably from their control group with recognition of object silhouettes (see Table 3).

6.1.3 Reading and global precedence effects: The DPs did not differ reliably form their controls in reading whereas they did exhibit a reduced global-local precedence effect (see Table 3). This is the reverse pattern to that found in the HP group.

6.1.4 Results from the dissociation analyses: In comparison with the HP group, that did not perform disproportionally better with faces than with words and objects, the DP group performed disproportionally worse with faces in nearly all comparisons (see Table 4). It was only when object silhouettes were compared to the CFPT that the DPs' performance was not disproportionally worse; while the dissociation was borderline significant for reading compared to CFPT (p = .06). Hence, the only commonality between the HP and DP groups is that for neither group is the performance on the CFPT disproportionally better (HP) or worse (DP) relative to their performance with recognition of silhouettes. It is still the case, however, that the HP group performed *better* on the both the CFPT and $ODT_{Silhouettes}$ compared with their controls, whereas the DP group performed *worse* on both tasks compared with their controls.

	Task correlation (*r*)	***p*-level of dissociation analysis**
CFMT & ODT_{Full}	.31	< .0001
CFMT & $ODT_{Silhouettes}$	.60	<.002
CFMT & $ODT_{Fragments}$	.11	< .0001
CFMT & Reading	-.33	< .001
CFPT & ODT_{Full}	-.44	< .002
CFPT & $ODT_{Silhouettes}$	-.42	.16
CFPT & $ODT_{Fragments}$	-.32	< .001
CFPT & Reading	.22	.06

Table 4: Correlations between tasks for the whole sample (developmental prosopagnosics and controls) and the

significance level of the dissociation analyses performed on the tasks (Crawford et al., 2000).

6.2 Interim discussion

As argued in the section on the HP group, there is no indication that HPs differ qualitatively from individuals with middle range face processing skills. Whatever differentiates performance in the middle portion of the population may also be what differentiates performance in the high end of it. Moreover, this ‘something’ does not seem more important for face processing than it does for processing of objects and words, and one could conceive of it as a general factor in the visual domain akin to the G-factor in intelligence; a VG-factor.

Turning to the DP group, the picture is clearly different. With only one real exception (the CFPT/$ODT_{Silhouettes}$), the face processing performance of this group is significantly more reduced than what would be expected given their performance with objects and words. This suggests that the DPs’ face processing performance does differ qualitatively from that of the normal population. To the extent that inversion effects are more pure measures of face processing ability than performance with upright faces alone, and one can argue that it is because all other parameters than face orientation are held constant across conditions, the reduced inversion effects observed for both the CFMT and the CFPT in the DP group point in the same direction (see also Klargaard, Starrfelt, & Gerlach (2018)).

One may argue that these results demonstrate that the DPs exhibit a face-specific problem. This, however, would not account for the fact that the DPs are also impaired with processing of inverted faces and recognition of silhouettes, and also exhibit a reduced global-local precedence effect (Gerlach et al., 2017) (for other non-face processing deficits in this group of DPs see Gerlach et al. (2016)). In line with our prior arguments (Gerlach et al., 2016), we thus think it is more appropriate to conclude that the DPs suffer from a deficit that is disproportionally more harmful for face than for object recognition; a performance pattern corresponding to a strong dissociation. For word recognition, on the other hand, the DPs do exhibit a putatively classical dissociation with within normal range reading ability and impaired face recognition ability, and a difference between these domains that exceeds what can be excepted in the normal population (Starrfelt et al., 2018). Considered together these findings suggest that face processing and object processing rely on some common process(es) that are not shared with word processing, and that it is these process(es) that are impaired in DP.

7. GENERAL DISCUSSION

In the series of experiments presented here, we have examined the performance of 14 individuals who contacted us because they experienced being better than their peers at recognizing faces, and who scored over 90% correct on the online version of the CFMT-Aus. Comparisons between these individuals and a matched control group, that was not selected due to their face processing abilities, on two tests of face processing (the CFMT and the CFPT) and a self-report questionnaire of everyday face recognition (the FEQ) confirm that these self-referred individual do on average exhibit superior face recognition skills. We refer to this self-referred group as high performers (HPs). We use this term not to confuse them with so-called super-recognizers, who are classified as such because they perform at a level of > 90% correct on the long-form of the CFMT (CFMT+), which was not used in the present study. It is possible, however, that some of our best performing HPs might have been classified as super-recognizers, had they performed the CFMT+.

There is still a limited number of reports of individuals with superior face recognition ability, be they HPs or super-recognizers (Noyes et al., 2017), and we know of only three studies (Bennetts et al., 2017; Bobak, Bennetts, et al., 2016; Davis et al., 2016) that have examined the main question we wished to address here: Is the superior performance of HPs limited to faces or is it characteristic of their performance with other stimulus classes (objects and words) also?

In comparison with the work of Bobak, Bennetts, et al. (2016), which was based on single case analysis of six individuals, our approach is based on group level analyses. Although there may be advantages associated with a single case approach, group level analyses are statistically more powerful. Also in contrast to Bobak, Bennetts, et al. (2016) and Davis et al. (2016), who provided no formal comparisons of performance with faces and objects for their super-recognizers relative to controls, our results are based on statistical dissociation analyses which are designed with this purpose in mind (Crawford et al., 2000). This methodological aspect is important because a pattern of within normal-range performance in object recognition and an above normal-range performance in face processing, the pattern reported by Bobak, Bennetts, et al. (2016) and Davis et al. (2016), does not in itself provide solid evidence that face and object processing are significantly different (Crawford et al., 2003; Gerlach et al., 2018).

Contrary to Bobak, Bennetts, et al. (2016) and Davis et al. (2016) we find that HPs exhibit superior performance on many tasks. Hence, they are not only reliably better at processing faces, relative to controls, but also at recognizing inverted faces, objects, object silhouettes, fragmented objects and words. However, it is worth noting that the HPs did not exhibit an across the board visual processing advantage as they did not perform better than the control group in Navon's paradigm, which taps low- and mid-level visual processes. This suggests that the HPs' superior performance in face, object and word processing is unlikely to reflect general differences between the groups in conscientiousness, general processing efficiency, or low-level factors such as visual acuity, as such difference should have led to group differences in Navon's paradigm also. Finally, in no instance did the HPs' face and object processing abilities differ more than they do in the control sample. In other words, we obtained no evidence suggesting a dissociation in the HPs' performance with faces relative to other stimulus classes. This suggests that whatever underlies the superior face processing performance in these HPs, this may also underlie their superior performance with other stimulus classes. At least we have no evidence suggesting a qualitative difference in the way that the HPs process faces relative to the controls, as such a difference should reveal itself as a dissociation. What exactly underlies this general superior performance calls for further investigation but until then we can conceive of it as a general factor in the visual domain, a VG-factor, akin to the G-factor in intelligence.

The failure to find any signs of a qualitative difference in the face processing performance of the HP group prompted us to examine whether the same held true for individuals with low face processing performance. We did this by assessing the performance of 10 individuals with developmental prosopagnosia (DP), who performed the exact same tests as the HPs (previously reported in Gerlach et al. (2016) and Starrfelt et al. (2018)), using the same dissociation analyses as the ones performed on the data from the HP group. The results from these analyses were rather clear-cut, in that the DPs in the majority of instances exhibited a clear dissociation in their performance with faces contra objects and words relative to their matched controls. For words we find a putatively classical dissociation with performance in the normal range for words and with below average performance for faces, and a difference between these domains that is significant. For objects we mostly find strong dissociations with impaired performance in both the face and the object domain, but a difference between these domains which is significant. Together, these findings suggest that face processing relies on some critical cognitive processes that are shared with object processing, but which are not important for reading. It is this, or these, process(es) that seem(s) impaired in DP. As we have argued elsewhere, a common denominator that can explain the pattern of preserved and impaired performance in our group of DPs may relate to problems in efficient use of global shape information (Gerlach et al., 2017, Gerlach & Starrfelt, 2018b); a type of information that is critical to both face and object recognition but of little relevance for reading (Starrfelt et al., 2018).

It is worth noting that Gerlach et al. (2016), based on the same group of DPs as examined here, came to the conclusion, that there was no evidence of dissociations in this particular group. This conclusion, however, was based on single case statistics. In comparison, the present analyses are group based. This testifies that group level analyses, due to greater statistical power, are more sensitive than single case analyses. Indeed, we believe that this may also be the reason why we find superior object processing performance in HPs when the study by Bobak, Bennetts, et al. (2016), which was based on single case analyses, found no such evidence. While there is an apparent contradiction between the findings of Gerlach et al. (2016), who report no dissociation between face and object processing in DP, and the new analysis of the same data reported here (finding evidence for differential deficits, with face processing being significantly more affected than object processing in DP), the main conclusion is the same: DP is *not* characterized by a selective deficit in face processing as object processing is also affected albeit to a lesser extent.

The relative sparing of object processing in DP is a question under intense debate at present (see Behrmann and Geskin, 2018; Geskin and Behrmann, 2018 for an overview). Positions differ widely, from the suggestion that object deficits in DP may be frequent, but principally unrelated to their face recognition deficits (Gray & Cook, 2018), to the suggestion that the many observed associations between deficits with faces and objects, and indications of a systematic relationship between the two, indicate a common explanatory factor (Gerlach et al., 2017, 2016; Geskin and Behrmann, 2018).

Returning to the comparison of the HPs and DPs our findings suggest that face processing in HPs does not differ qualitatively from that of the normal (middle range) population whereas it does in DP. A similar conclusion, suggesting that super-recognizers represents the high end of a normal face recognition spectrum, while face processing in DPs is qualitatively different from normal viewers was reached by Bobak et al. (2017). Hence, there seems to be a qualitative difference that distinguishes DPs from individuals who are just “bad at faces” to paraphrase Barton & Corrow (2016). As we alluded to above, however, the problem is that this difference seems difficult to capture on the single case level. Consequently, a future challenge will be to develop tests that are sensitive enough to capture this “global shape deficit”, and impairments in the object domain, on an individual basis.

Our conclusion, that HPs do not differ qualitatively in their face recognition abilities relative to other middle-range performers, should be seen in the context of three potential limitations of the present study. The first limitation is that there were ceiling effects on one of the test employed (the CFMT) for a subset of the sample. This means that that the difference between this particular test and the object and reading tests may have been restricted. The fact that we obtained similar results with another widely used test (the CFPT) that is not subject to ceiling effects dampens this concern. Since the CFPT was designed to test face perception deficits, it may be less suitable for examining the high end of face perception abilities on the individual level (for a discussion of the suitability of this test in superior face recognizers, see Bobak, Pampoulov & Bate (2016)). However, we did find a reliable difference between HPs and controls on this task, which suggests the task is sensitive enough to discriminate performance on a group level. The second, and somewhat related, limitation is that we did not confine our HP sample to include only the absolute extreme end of the face processing continuum; the so-called super-recognizers, as would have been the case if the experimental group was selected using the CFMT+ combined with a conservative cut-off. While we acknowledge this limitation, we will note that our HP group *did* perform significantly above average, which illustrates that this group can be differentiated from normal participants. Consequently, it will be difficult to find a group that outperforms our HPs on a group level. Should this nevertheless be accomplished, one possible outcome may be that such a group will also exceed our HPs in object processing performance. In that case, the conclusion will be the same as the one drawn here. Further, and from a methodological point of view, one also has to consider the limitation in identifying a specific segment of a population by means of performance on a single test considering that top-performance on one face recognition test is not necessarily associated with top-performance on another face recognition test (Noyes et al., 2017). The last limitation concerns the fact that our conclusion is partly based on negative findings, namely lack of dissociations. Consequently, this conclusion will be challenged if a dissociation can be established in other HPs (or super-recognizers) using other tasks. As an example, it is possible that another segment of individuals may achieve their superior face performance by means of resources not shared by the object processing system. In that case, two types of HPs will exist; those with and those without superior object recognition skills. This would definitely be an interesting finding.

8. REFERENCES

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Competing Interests

The authors declare that no competing interests exist.

Highlights:

- We tested good face recognizers, controls, and developmental prosopagnosics (DPs)
- Face, object, and word recognition were significantly better in High Performers
- No qualitative difference was found between High Performers and normal viewers
- Significant dissociations were found between face and object recognition in DPs
- Face processing is disproportionally affected in DPs compared to normal viewers